

Fragmented Distribution of a Rock Climbing Fish, the Mountain Galaxias *Galaxias olidus*, in the Snowy Mountains

KEN GREEN

Snowy Mountains Region, National Parks and Wildlife Service, PO Box 2228, Jindabyne NSW 2627.

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Fish were surveyed visually from 1,500 m elevation to the highest known altitude for Mountain Galaxias *Galaxias olidus* of 2,137 m on the slopes of Mt. Kosciuszko (2,228 m). Above 1,500 m, where the species is the only galaxiid and is physically isolated from all lowland populations, there was further isolation with 76 disjunct populations within the 1,400 km² area surveyed. Trout (Salmonidae) were the main cause of this isolation because they occupied 95.85 km of the major streams, generally in the main valleys at lower elevations but reaching up to 1,800 m in places, and leaving only the headwaters unoccupied. The distribution of *G. olidus* above 1,500 m was, therefore, determined largely by topographic and anthropogenic barriers to the movements of trout. Despite being recorded as absent from western drainages in the mountains, including two of the five glacial lakes, since as long ago as the 19th century, *G. olidus* moved into Australia's highest lake (Lake Cootapatamba) during the course of the survey with serious implications for biodiversity in this newly occupied lake.

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INTRODUCTION

The Mountain Galaxias *Galaxias olidus* is found from sea level to above the treeline in the Snowy Mountains (McDowall and Frankenberg 1981; Green and Osborne 1994). Throughout its range it has a widespread, though fragmented, distribution, largely due to the effect of alien trout (Salmonidae), and is most commonly found in the smaller headwaters of streams or above some obstacle to upward movement by trout (Cadwallader and Backhouse 1983). The higher altitudes of the Snowy Mountains that support a winter snow cover for at least one month per year (>1,500 m a.s.l.) drain into tributaries of the Murray and Snowy Rivers. Many of these tributaries have been stocked with trout and most have been impounded at one or more points along their length for generation of hydro-electricity and for irrigation. The high altitude populations of native fish are therefore isolated from lowland populations by a number of barriers. Within this high altitude area, there is further subdivision of the contiguous area above 1,500 m (Fig. 1). This area is bounded on the north and east by the Eucumbene

River. This, together with the Thredbo River that drains much of the southern boundary then joins the Snowy River above Jindabyne Dam where the Mowamba River also arrives through an aqueduct. Below the dam, only the Jacobs River, draining areas above 1,500 m, continues to flow unimpounded into the Snowy River. On the western side, the main drainages in the north and west, the Tumut, Tooma, Geehi and Swampy Plains Rivers and Bogong Creek are dammed and, of the major catchments, only water bodies from Leatherbarrel Creek (Fig. 2) southward flow unimpounded into the lowlands (<400 m elevation) where they join the Murray River.

In this mountain area above 1,500 m (the subalpine and alpine zones) there is only one native species of fish, *G. olidus* (Green and Osborne 1994). Although currently treated as one species, there are several forms of *G. olidus* (Raadik 2001; Raadik and Kuiter 2002). Ogilby (1896) stated that above the winter snowline, a stout, sombre-coloured form was found in deep, still pools and smaller ponds while a slender, brilliant-coloured form occurred in rapidly moving waters with gravelly or sandy shallows.

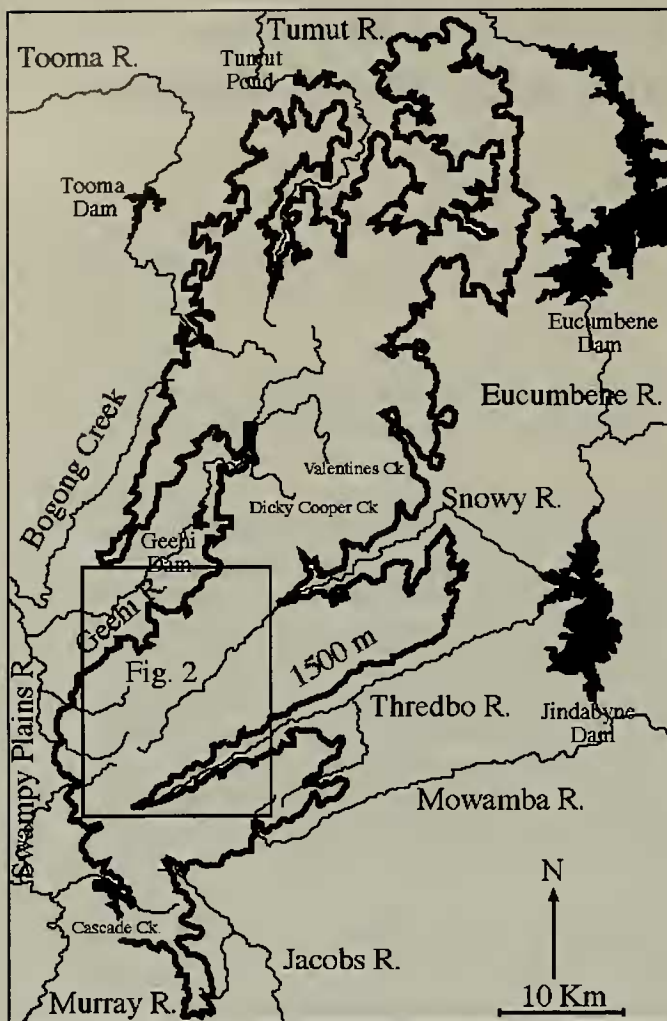


Figure 1. The study area showing the largest contiguous area of the Snowy Mountains above the 1,500 m contour and the main rivers and dams essentially isolating *Galaxias olidus* within this area.

Between the two extremes, 'every conceivable variety, both of contour and colour may be found' (Ogilby 1896). There is also a high level of genetic distinctiveness of populations of *G. olidus* across the landscape (Raadik and Kuiter 2002; T. Raadik pers. comm. 2006).

The salmonids Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*), native to the northern hemisphere, were introduced into the Snowy Mountains in the nineteenth century, with the Brook Trout (*Salvelinus fontinalis*) and the Atlantic Salmon (*Salmo salar*) introduced later (Cullen and Greenham 1980). However, only the first two are now common in the Snowy Mountains. The upstream invasion of the mountain streams from introduced stock has resulted in a fragmentation of higher elevation populations of *G. olidus*. Trout are a major threat to many native Australian fish species, particularly galaxiids and, 'completely replace galaxiid populations, leading to local extinctions' (Raadik and Kuiter 2002). The

consequences of the invasion between 1971–1974 by *O. mykiss* of a stream containing only *G. olidus* was documented by Tilzey (1976). Later, Lintermans (2000) documented the re-invasion of a montane stream by *G. olidus* once *O. mykiss* was removed.

The aim of the present study was to survey the high altitude streams of the Snowy Mountains (> 1,500 m elevation) to determine the extent of the invasion by trout and to assess the degree of isolation of remaining populations of *G. olidus*.

METHODS

Climbing of wet rocks by *G. olidus* was recorded on video camera in a tributary of Dicky Cooper Creek at the location that climbing by the species was first described by Green (1979). The video was watched in slow motion in an attempt to observe the method of climbing. To examine the mechanism of climbing, the lateral surfaces of *G. olidus* collected from the outlet creek of Lake Cootapatamba were examined beneath a dissecting microscope and photographed.

Mountain streams above 1,500 m were chosen for survey from maps at a scale of 1: 50,000 for the whole Snowy Mountains and at 1: 25,000 for the Kosciuszko Main Range. These streams and additional ones observed in the course of the survey were walked over a period of three years, December 2004–May 2007. Stream waters were extremely clear, and streams were investigated visually only on calm days. Fishes clearly above the maximum length of *G. olidus* (135 mm -McDowall 2006) were recorded as trout. No attempt was made to differentiate the species of salmonid further because their fry are difficult to identify (Tilzey 1976). Fish in the size range of *G. olidus* were inspected with binoculars to determine species. Differing behaviour and colour pattern were good indicators of species, but identification of all fish was based on the location of the dorsal fin, high on the back in trout and located well back on the body in *G. olidus*. Reference specimens of *G. olidus* were collected only from the outlet creek of Lake Cootapatamba. Streams were investigated upwards from the 1,500 m contour with species of fish and any barrier to their upstream movement recorded. These streams were walked below and above these barriers (such as waterfalls sufficiently high to exclude trout) until no further trout were seen and the presence or absence of *G. olidus* was recorded. Because absence cannot be confirmed, streams in which *G. olidus* was not recorded were walked until they became a trickle or dried up completely. Streams checked from higher altitude downstream were checked only until trout

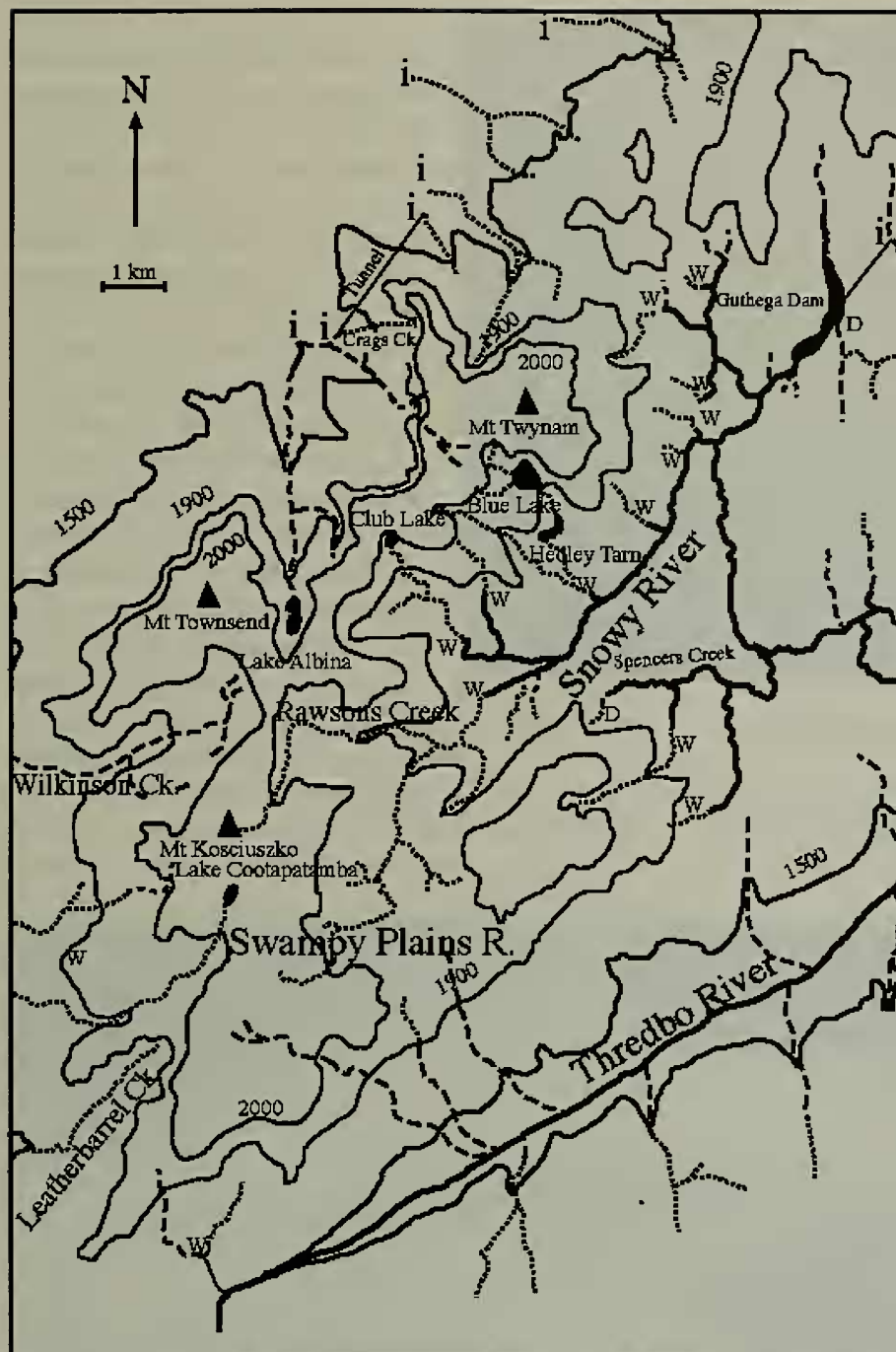


Figure 2. One of the two largest stream complexes in the Snowy Mountains containing *Galaxias olidus*, together with the five glacial lakes and the factors isolating the populations. Rivers with dotted lines contained *Galaxias olidus*, dashed lines no fish seen, solid line trout. W = waterfall, i = water intake, D = dam.

were the only fish observed in the stream or until the 1,500 m contour was reached (although some streams were descended further).

The species 'trout' and/or *G. olidus*, together with barriers above which one or both species were missing were recorded on a hand-held GPS. All locations were plotted onto maps at 1: 50,000 and the length of streams occupied by trout was measured using a map wheel.

The presence of *G. olidus* at its highest elevation (in the headwaters of Rawsons Creek) was recorded

regularly throughout the snow-free seasons to determine date of arrival and departure of fish. This was at the upper limit of surface flowing water in the Snowy Mountains where the water pooled at a drain with a depth generally <30 mm on a rocky substrate in an area of < 1 m², before being diverted through a culvert beneath the Mt. Kosciuszko summit walking track. Presence or absence was therefore easy to determine.

RESULTS

Evidence from the video of climbing by *G. olidus* showed that while in contact with the rock *G. olidus* lay with pectoral and anal fins flattened against the rock. Propulsion was by using the fins as independent limbs and 'walking' (or rather scuttling) up the rock. Examination beneath a dissecting microscope and subsequent photographs (Figs 3 and 4) show that both the pectoral and anal fins have rugosities on the ventral surfaces that might be used in climbing.

Within the 1,400 km² of contiguous land above 1,500 m altitude, salmonids occupied 33 water courses totalling 95.85 km, generally at the lower elevations but reaching up to 1,800 m in a number of tributaries of the upper Snowy River (Figs 1 and 2). Only one stream system, Valentines Creek, had trout and *G. olidus*

coexisting in the same reaches. *Galaxias olidus* was recorded from 86 stream systems with 76 of these being isolated from other water bodies containing *G. olidus* by trout downstream. There were only two large complexes of streams containing *G. olidus*, both protected by waterfalls at the downstream ends of their range, these were the upper Geehi River system and the upper Snowy River system (Figs 1 and 2). Elsewhere, *G. olidus* occurred only in isolated streams. The fine scale disjunct distribution of *G.*



Figure 3. The lateral surfaces of the pectoral fin of *Galaxias olidus*.

olidus is illustrated for the Main Range of the Snowy Mountains, which comprises 15% of the area above 1,500 m with 28 isolated populations in about 200 km² of the highest country in Australia (Fig. 2).

The lower limits of distribution of *G. olidus* were set by features thought to be impassable to trout. Situations where *G. olidus* was isolated from trout included galaxiid occurrence in enclosed ponds (three complexes within areas otherwise dominated by trout), anthropogenic barriers (11) and waterfalls (33). Barriers such as waterfalls, chutes and artificial interception of flows (for aqueducts) that blocked trout movement, blocked upward movement of all species at different locations. Anthropogenic structures were either themselves a barrier, or caused a barrier to fish movement by eliminating water flow in some downstream reaches of streams.

Galaxias olidus was recorded up to an altitude

of 2,137 m, just 91 m lower than the summit of Mt. Kosciuszko. Here two streams, tributaries of Rawsons Creek, narrowed to trickles 5-10 cm wide and less than 1 cm deep, and in places flowed over grass, below culverts under the Mt. Kosciuszko summit walking track. Above the culverts, drains fed by seepages off the side of Mt. Kosciuszko maintained semi permanent water bodies.

Galaxias olidus was restricted in upward movement by waterfalls that exclude it from Wilkinsons Creek complex and from many of the steeper streams on the western faces of the Main Range (Fig. 2). Steep streams on the northern side of the Thredbo Valley generally also lacked fish. These streams lacked large waterfalls but were

generally small and fast-flowing with few pools. Additionally many had long areas of continuous cover



Figure 4. The lateral surfaces of the anal fins of *Galaxias olidus*.

of shrubs, particularly tea tree (*Leptospermum* spp.) that shaded the streams. Where *G. olidus* did occur in a particular stream few were recorded in similarly shaded reaches.

For the first time ever, *G. olidus* was recorded in

Australia's highest lake, Lake Cootapatamba (2,050 m). During the survey, *G. olidus* was noted in the stream draining Lake Cootapatamba in December 2004 and again in mid November 2005 but not in the lake. It was first noted in the lake on 9 Jan 2006 and by March 2007, a school covering approximately 2 m² in shallow water near the outlet contained an estimated 2,000 fish.

Fish were commonly seen above the Kosciuszko summit walking track in two small ponds at the headwaters of Rawsons Creek and during this study were first noted on 9 and 18 November in 2006 and 2005 respectively. In 2005 they were last observed on 2 May. In 2006 they were last observed on 20 March and, by 11 April, the area was covered in snow and remained that way for the winter. On 30 Mar 2007, with an almost full cover of snow, *G. olidus* was still present, but had departed by 19 April when none could be found. Fishes remained in the ice-covered Blue Lake, Hedley Tarn and Club Lake throughout winter. One fish was observed swimming beneath the ice of Club Lake on 15 Jun 2007 and fish were seen in a part of the lake that thawed early in September 2006, whilst the outlet was still blocked by snow and ice, indicating that they had wintered over in the lake.

DISCUSSION

Rock climbing

To understand the distribution of *G. olidus* we need to understand its ability to ascend steep streams and survive in shallow water. McDowall (2006) considered that *G. olidus*, unlike *G. brevipinnis*, does not have a reputation as a good climber. In fact, *G. olidus* is very capable of climbing on vertical or even overhanging rock, as first reported from the Snowy Mountains by Green (1979), however, specimens that were collected at the time were originally misidentified as *G. brevipinnis*. The fishes observed by Green (1979) were 30 to 60 mm long, climbing being probably aided by their small size giving them high surface area to weight ratio (McDowall 2006).

Climbing by *G. olidus* includes at least three important elements. The ability to jump out of water, to a height at least four times its length (Green 1979), allows it to gain contact with surfaces that do not extend to water level. The next important ability is to adhere to the rock, whether establishing contact immediately after a jump or maintaining contact whilst climbing. The third ability, while retaining adhesion, is to gain propulsion for climbing. Green (1979) wrote that *G. olidus* lacked any specialized

organs for adhesion and appeared to rely upon the surface tension of a thin film of water between its ventral surface and the rock, as also suggested for diadromous *Galaxias* by McDowall (2006). As with *G. brevipinnis* (McDowall 2006), downward facing pectoral and anal fins provide surface contact in *G. olidus*. In addition to adhesion, these fins were also observed to be important in propulsion. McDowall (2003, 2006) illustrated the rugosities on the ventral surface of pectoral fins of *G. brevipinnis*, and the present study has found similar rugosities on the ventral surfaces of both the pectoral and anal fins of *G. olidus* (Figs 3 and 4).

Despite its climbing ability, *G. olidus* was absent from a number of streams at high altitude that apparently have never held trout or galaxiids. Green (1979) noted that the successful climbers were those that kept out of the main flow of falls but remained on rock adjacent to the main flow, that was only occasionally washed by water. In certain circumstances wet rock may not occur adjacent to the main flow (where the water flows over an overhang and drops sheer) or the moist zone may be unsuitable (such as where it becomes a haven for moss).

Isolated populations

McDowall (2006) has shown that throughout the cool temperate southern hemisphere, with few exceptions, galaxioid fishes are adversely affected by introduction of trout, with a major decline in the Galaxiidae in particular. The general pattern of fish distribution in the Snowy Mountains and Victorian Alps is one of trout occupying the main stream, while *Galaxias* spp. are usually only found in upstream water bodies inaccessible to trout (McDowall and Frankenberg 1981). Jackson (1981) stated that, 'above the snowline, instances of trout being the only fish below a waterfall and *Galaxias* the only fish above the waterfall are common in our experience.'

Tilzey (1976) sampled a stream in the Lake Eucumbene catchment in the Snowy Mountains twice in the course of three years during which time the stream was invaded by Rainbow Trout. In 1971 the stream contained only *G. olidus* below a waterfall but by 1974 trout had spread upstream as far as the waterfall and *G. olidus* had disappeared. This same pattern occurred in the present study. Throughout the Snowy Mountains in the 1,400 km² of land above 1,500 m, there were 76 isolated populations of *G. olidus*. Infiltration of trout was the major cause of this isolation, and they occupied 33 water courses totalling 95.85 km downstream of populations of *G. olidus* and separated from them mainly by waterfalls. A secondary isolating mechanism was anthropogenic

– dams for aqueduct intakes isolating upstream from downstream reaches of the same stream. The third cause was isolation within ponds (such as those near Mt. Clarke) that are currently well separated from other water bodies. Connecting water courses may have existed in the past possibly as erosion runnels, particularly as a result of cattle grazing activity that has since ceased, allowing the runnels to revegetate as recorded elsewhere (Green et al. 2005; Green pers. obs.).

The failure to find *G. olidus* in the upper regions of some trout-accessible streams (where trout are, however, lacking) may be because the reaches are uninhabitable in some seasons (under ice) or some years (drought) or because, as downstream migration results in predation it cannot be balanced by upstream migration. Also we cannot now tell which headwaters have had introductions of, or have been invaded by, trout in the past resulting in the extirpation of *G. olidus* followed by the loss of the trout. Similarly, some streams had no trout during this survey although they appeared suitable, and instead had very low numbers of *G. olidus*. This may have been caused by a die-off of trout in warm waters in the drought that took place over most of the survey period, followed by a re-invasion by *G. olidus* of these waters as observed in Victoria by Closs and Lake (1996). If this re-invasion also implies continuous downstream movement by *G. olidus* when trout were present then this would result in a continuous loss of individuals to predation (McDowall 2006). However, where there were refuges such as shallow, warm anabranches as in Valentine Creek, both trout and *G. olidus* occurred. The trout were present in low numbers and the *G. olidus* were in considerably lower numbers than in nearby streams without trout.

Macleay (1882) described galaxiids from the higher altitudes of the Snowy Mountains ('captured ... on Mt Kosciusko') as *G. findlayi*, but the type specimens were subsequently lost (Raadik and Kuiter 2002). Helms (1890) collected specimens possibly in Diggers or Pipers Creek (Raadik and Kuiter 2002), and the species was later reported from the headwaters of the Snowy and Thredbo Rivers (Ogilby 1896). It is possible that the exact sites where these original collections came from may still support *G. olidus*. One stronghold of the species is the higher altitudes in the headwaters of the Snowy River (Fig. 2) and *G. olidus* was recorded in the headwaters of both Diggers and Pipers Creek, and although it could not be found in Thredbo River it did occur in isolated headwaters of some tributaries.

Some populations have possibly been isolated for periods of years if not decades and that isolation may

be permanent. For example, ponds along Valentines Creek are as high as two metres above the water level of the creek. These ponds would presumably flood exceedingly rarely and with already reduced snowfall (Green and Pickering 2002) and with predictions of further reductions in total precipitation (Whetton 1998) the flood conditions needed to inundate these ponds may not occur again. Ponds near Mt. Clarke have no nearby water course, and survival of *G. olidus* in them demonstrates the resilience of the species as also demonstrated when depleted oxygen extirpated Common Carp *Cyprinus carpio* but not *G. olidus* (Lake 2003). As a result of the drought the Mt. Clarke ponds dried up for an extended period between 17 Feb and 20 Mar 2006, and no water was visible on the surface on 13 March. However, once rains came, fish reappeared in the ponds having survived the intervening weeks, presumably in burrows of *Euastacus* sp. *Galaxias olidus* is known to travel in underground sections of streams (Lintermans 2000) and probably does so in the many water bodies in the Snowy Mountains that have underground sections incised into a bog. However, the ability to remain underground during drought for this length of time is an interesting response to existence in the ephemeral headwaters of streams and ponds. In the same period, *G. olidus* at the highest altitude in the headwaters of Rawsons Creek was cut off from the main water body when the outlet from the drains it was in dried up, but it was able to remain in a small seepage until conditions improved. Its survival in Club Lake over winter is also of interest because the ice sits on the mud floor of this lake even in poor snow years constraining the possible over wintering locations for *G. olidus*.

Limitations to upstream movement

Because *G. olidus* can move in small trickles, it can ascend right to the headwaters of streams and this makes it impossible to put an upper limit on its distribution in any network of streams. *Galaxias olidus* penetrated to streams above the summit walking track of Mt. Kosciuszko by November of each year, and departed once the ice from the first heavy frosts appeared on the water, at times varying between April and May. Walford (1928) mentioned *G. olidus* seeking lower altitudes in winter 'about Mount Kosciusko' but gave no other details. However, fish remained under ice in Hedley Tarn, Blue Lake and Club Lake, indicating that cold itself was not a major factor, although in shallow waters, physical contact with the ice may have to be avoided to prevent injury.

The valley wall on the southern side of the Thredbo River, a major trout river, is very steep

and, between the confluence with the Little Thredbo River in the east and Dead Horse Gap in the west, five isolated populations of *G. olidus* were recorded, all above waterfalls. The northern side, with a similar gradient, however, lacked *G. olidus* except in one arm of Bogong Creek and the headwaters of a creek on Merritts Spur. The isolating factor here may just be the continuous steepness of the creeks and the general overgrowth of tea tree (*Leptospermum* spp.) in the lower reaches. Although *G. olidus* is able to travel in underground sections of streams (Lintermans 2000), densely shaded reaches of stream were not normally inhabited, and open reaches of such streams above or between shaded areas also often lacked fish. This shading may have been sufficient to prevent the ascent of *G. olidus* into apparently suitable waters arising between North Ramshead and Ramshead. *Galaxias olidus* may also be intolerant of continuous steep gradients, as its favoured location appears to be in slow flowing stretches and pools beneath waterfalls and riffles (pers. obs.). However, not knowing the history of some of these waters, trout may once have been introduced. However, between Bogong Creek in the SW and the lower reaches of Lady Northcote Creek in the NW, *G. olidus* has historically been absent above 1,500 m including the two lakes in these catchments Lake Cootapatamba and Lake Albina (Fig. 2). Anthropogenic barriers constructed in streams above naturally occurring barriers to the movement of trout have isolated populations of *G. olidus* on the western faces. Waterfalls, however, have been the main limiting factor historically to the upstream spread of *G. olidus* on this side. The upward movement of *G. olidus* appears to have been barred at about the 1,500 m contour in a number of streams on the western side at large waterfalls, possibly due to a band of rock at that altitude more resistant to erosion. Such falls occur on Wilkinson's Creek, which still has no *G. olidus* in its upper reaches (although it must occur lower because this is a tributary of Swampy Plains River from which the fish in Lake Cootapatamba ascended). Once above the falls on Swampy Plains River, *G. olidus* ascended into two main tributary arms including that flowing from Lake Cootapatamba.

Lake Cootapatamba

Helms (1890) wrote of Lake Cootapatamba and Wilkinsons Valley, 'the absence of *Galaxias* at this elevation struck me as peculiar. It is, however, remarkable that on the Snowy River side these fishes are met with almost everywhere.' *Galaxias olidus* was not recorded in Lake Cootapatamba at any time in the 20th century despite a number of investigations

of the lake (Green and Osborne 1994). Neither were fish recorded in Lake Cootapatamba by Timms (2002). However, in the present study they were found in Swampy Plains River, which flows out of Lake Cootapatamba, as early as December 2004. By mid November 2005 they were still found in the outlet creek but not in the lake, but in January 2006 they had progressed upstream into the lake. Along the western fall of the Snowy Mountains from Crag Creek that empties into the Geehi River (Fig. 2), 24 km south to Cascade Creek that flows into the Murray River (Fig. 1), no *G. olidus* were found except in two catchments. In both Leatherbarrel Creek and Swampy Plains River, *G. olidus* was found in 2004. There is no barrier to movement of these fish from a waterfall at about 1,500 m to Lake Cootapatamba, and certainly nothing that would seem likely to delay the arrival of *G. olidus* by over 110 years since the visit by Helms (1890). It would appear that *G. olidus* ascended this waterfall sometime between 2002 and 2004. An obvious issue here is the role of a major fire in the area in 2003. Elsewhere during this survey it was observed that debris from the fire washed down creeks and formed dams that raised the water level below waterfalls. If such an occurrence took place below a waterfall that had previously prevented upstream movement it could have the effect of aiding the ascent by *G. olidus*.

Translocation of galaxioids into new areas has caused adverse impacts (McDowall 2006). The spread of *G. brevipinnis* from eastern catchments into the drainage of the Murray River due to diversion of streams for hydro-electricity and irrigation has been of concern (McDowall 2006), although the impacts of this are not clear and the species appear to be cohabiting (T. Raadik pers. comm. 2007). An expansion of *G. olidus* into Lake Cootapatamba might have serious consequences, and because a lake ecosystem is not as open as a stream, the effects of changed predation patterns on biodiversity might be dramatic. Already the Kosciuszko endemic cladoceran *Daphnia nivalis* seems to be in decline and studies of the impact over the next few years will be crucial in understanding this impact (Yoshi Kobayashi pers. comm. 2007).

Conclusion

If the mountain galaxias was just one species also found at different locations down to sea level, the disjunct distribution in the Snowy Mountains could perhaps be seen to be of only academic interest. However, because it is widespread, there is currently no explicit concern for its conservation (McDowall 2006). Even so, isolation at the local scale can have serious consequences because small populations

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are more susceptible to declines from stochastic effects, be they ecological or genetic (McDowall 2006). Although McDowall and Frankenberg (1981) brought together a group of poorly defined taxa under *G. olidus* (McDowall 2006), it appears that this is a species complex (Raadik 2001; Raadik and Kuitert 2002). There is a possibility, therefore, that some of the species in this complex may occur as isolated populations and may be at risk owing to the failure to recognise these new taxa, and so there is a danger that appropriate conservation measures might not be considered until it is too late (see McDowall 2006). Pond-bound populations may also die out in droughts, and groups trapped above permanent barriers (such as hydro-electric infrastructure) are at long-term risk from inbreeding. Loss of any of these isolated populations would at least result in reduction of the species' genetic diversity, but may result in loss of discrete taxa and could have series effects on ecosystem function (McDowall 2006).

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